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CONDITION AND FUTURE USE OF EARLY AGE STEEL BRIDGES IN A HISTORIC CITY

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Keywords: early age steel bridges, design load, assessment by real traffic data, condition of historic bridge, refurbishment alternatives.

Abstract. *Due to its location at the confluent of rivers Scheldt and Lys and the many canals and ditches, built to overcome flooding, the historic city of Ghent has many bridges. Their number decreased after covering many waterways. Presently, of the 124 left, the oldest are vaulted arches and in good condition. In addition, every 30 year period large refurbishments have been made and even total replacement according to original structures has occurred for 5 bridges. The condition of 2 early-age steel portal frame bridges, used by buses and tramways is the most critical. Possible design loading schemes, used at the time of their construction, are considerable lighter and do not comply with present codes. Careful numerical analysis and the use of realistic loading schemes, supplemented by detailed inspection, has allowed to establish a clear view on the remaining load carrying capacity. In spite of some heavy corrosion, reducing the dead load on the walkways may very well be sufficient to obtain sufficient load carrying capacity, without changes of the appearance and function of bridge parts, thus extending the life of these bridges.*

1 INTRODUCTION

Apart from Roman settlements, the oldest part of the city of Ghent was founded around 892 AC near to the confluent of the rivers Lys and Scheldt [1]. These rivers and their side arms caused regular floods, threatening the developing town. One way of dealing with the problem consisted of building smaller canals and ditches to increase the water retaining capacity. In addition, a connection to the sea was sought for many decades, by digging canals and connecting various waterways. Hence, the medieval city showed an impressive number of waterways, crossed by various bridges. In this growing urban environment, the 14th century saw the culmination when the number of inhabitants reached 64000, making Ghent the second city of Europe, after Paris. Many bridges have disappeared today, since in the 19th century, waterways were covered in many European cities, as they were considered to spread cholera and typhoid.

Today, the number of bridges is limited to 124, of variable types. This is due to a major event that reshaped many parts of the medieval city, the world exposition of 1913. At the dawn of WW 1 and in view of this event large parts of the city were transformed, several medieval buildings and churches were thoroughly refurbished. Among these, movable bridges were replaced by fixed crossings. At this particular period, steel was a new building material and the necessary craftsmanship was being implemented. Today, these structures are more than 100 year old and still used by modern traffic. For the owner, it is important to know the load carrying capacity of these bridges and to be able to assess refurbishment procedures. In the following, a closer view of the city's bridges is presented. In addition, the design loads of the past are commented and the paper focuses on 2 critical early age steel bridges.

2 BRIDGE TYPES AND CONDITION

2.1 Bridges

Of the remaining 124 bridges in Ghent, only 7 are authentic vaulted arches, built from sandstone or brickwork. These are all concentrated in the Northern part of the old town, where river Lys has not been navigable, already for a long time and the XII-th century canal Lieve towards the sea is closed down. Typical bridges are the Saint-Anthony bridge (left), rebuilt in concrete in 1954 and the Rabot bridge (right) oldest bridge in Ghent, built in 1860, both shown in Fig. 1.

Figure 1: Lieve bridge (left) and Rabot bridge (right).

None of these bridges is original and most of them were rebuilt in the 1950's, replacing metal bridges from middle or late 19th century. The first of 2 particular vaulted arch bridges is the 160 m long covering of the oldest branch of river Scheldt. This was built in 1886 on scaffolding and is commented in [2]. The second stone arch bridge is the well-known Saint-Michaels Bridge, an excellent viewpoint to see the 3 Ghent towers. This structure, built especially for the 1913 world exposition, is in almost excellent condition, as shown in fig. 2.

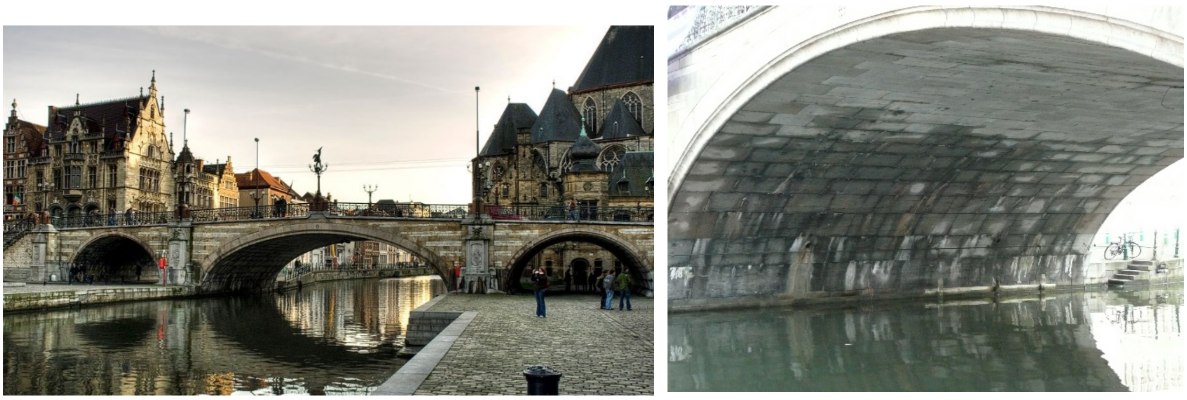

Figure 2: St-Michael's bridge across river Lys.

In order of age, these vaulted arch bridges are followed by a series of iron and early age steel bridges. In this series the E. Peynaertbridge, across an eastern branch of river Scheldt has luckily survived the many demolitions. This iron bridge, dating from 1883 consists of parallel I-profiles, connected by crossbeams. It is in acceptable condition as can be verified in fig 3 (left) and is used by local traffic. Apart from this bridge, apparently forgotten in any demolishment plans, a similar structure crosses the Cauldron canal, which was dug out already in the XIth century to demarcate the city limits. The Walpoortbridge is seen to the right of Fig. 3 and is already from early steel. The design and style are very close to the Peynaertbridge.

Figure 3: E. Peynaert bridge river Scheldt (left) and Walpoort bridge (right).

The 3 early age steel bridges, rebuilt for the 1913 exposition are discussed further. From 1984 to 1987 5 movable bridges were completely renewed according to the former design, including the use of riveted connections. All of them are swing bridges and the swing mechanisms have equally been replaced. Some of these have plain webs as the Grass Bridge (see fig. 4 left) and others have complex truss girders as Vleeshuis Bridges (fig. 4 right).

Figure 4: Rebuilt movable bridges. Grass Bridge (left) Vleeshuis Bridge (right).

The 5 rebuilt bridges were again thoroughly refurbished from 2012 to 2016, during periods of interruption to all traffic (including tramways), mostly by repainting and replacing the wooden deck. The bridges were completely wrapped and opened for shipping. In future, no motorized traffic will be allowed in the city centre. This will certainly increase the life cycle of all bridges. Finally, in 1973 one of the movable bridges was demolished and replaced by a movable cable-stayed bridge. The pylons are turning on wheels, supported by a concrete platform, easily seen in fig. 5 (left). During movement the pylons are vertically aligned by short stays, identical to the fan-arranged upper stays. This was a successful change and was followed by the replacement of the Kromme Wal Bridge, which then dated from 1872 and was a swing bridge. The new bridge was built in 1993 as a bascule bridge with the particular characteristic the counterweight is not fixed. The ballast box is normally empty and is filled with water from River Lys, when opened for shipping. The success of these bridges had led to the construction of other small pedestrian cable-stayed bridges, like the Emperor Park Bridge across lower River Scheldt and the Opera Bridge across the Cauldron Canal. Finally in 2000 a steel girder bridge was built across Lieve, as a pedestrian bridge, mainly for allowing modern visual arts as statues to be related to the historic river.

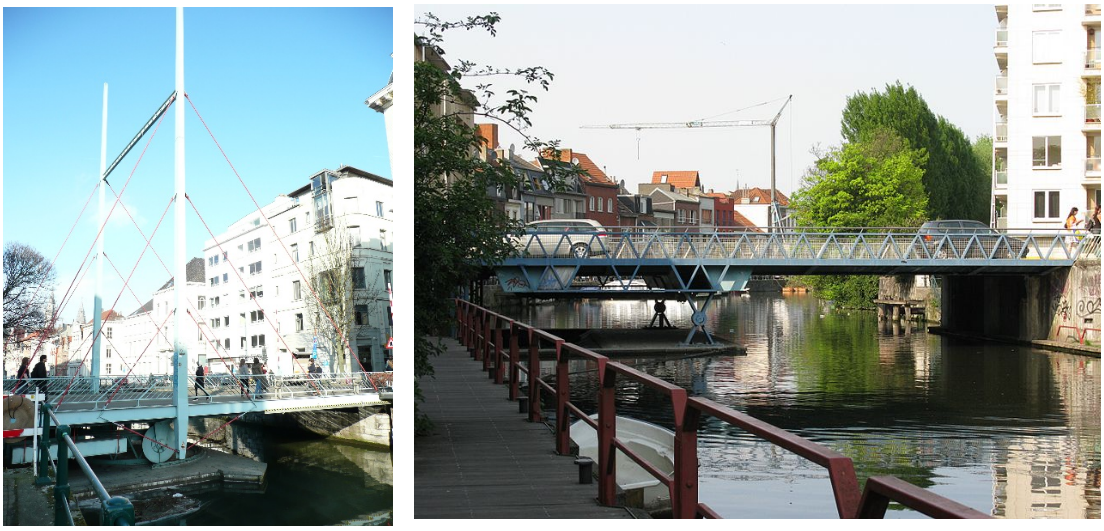

Figure 5: Replaced movable bridges. Predikheren bridge (left), Kromme Wal Bridge (right).

2.2 Traffic plan

From April 2017 a new traffic plan will be operational in Ghent. The car-free area is doubled and some important roads will be cut. Later in 2017 the plan will be evaluated. Nevertheless this plan also includes that traffic is fundamentally changed for some bridges. For instance the Barge Bridge, the largest of 3 steel portal frame bridges built in 1912 will be limited to pedestrians and cyclists. Generally, historic buildings and structures receive ill maintenance if the function is reduced or annulled. Hopefully the new traffic plan does not mean the beginning of a new period of poor maintenance and subsequent loss of a series of historic bridges.

2.3 Bridge's condition

Apart from 3 cases, all bridges are in good condition. Obviously, periodic inspection and maintenance are needed. The fact that some steel bridge superstructures were closed to traffic and completely refurbished also contributes to their satisfactory condition. However, looking at the maintenance dates, the interval between these actions reaches a value of about 30 years. This is excessively long and has led to costly maintenance operations, like total traffic interruption. Moreover, the bridges reported in section 4 suffered from such large damage that the owner considered demolishment of these heritage structures. In addition, the public transport company, unwilling to compromise on tram alignments [3] is pushing towards inappropriate actions or total replacement of bridges.

3 STRUCTURAL ASSESSMENT METHOD

3.1 Historic load

Bridges dating from the beginning of the 20th century were obviously not designed for the load schemes as recommended by the present codes [4]. In particular the LM 1 considers high concentrated loads and axles masses. There is not the slightest chance that historic bridges will pass the test of these design loads. Hence, it is most relevant to collect data concerning former load models. A small research, not claiming completeness or absolute truth, is reported hereafter and applies to roads in Belgium only.

According to literature [5], axle and wheel loads on curved arches were to be reduced to distributed loads. The intensity of these distributed loads corresponded to 4 kN/m². In [5] examples of this are given, for arches only. However, already in 1877 [6] wheel loads were introduced (by a minister's decree of July 9th 1877) clarifying that the 4 kN/m² represents a crowd load and alternatively, a force of 60 kN, representing a crusher roller, followed by a vehicle having axle loads of 40 to 60 kN and distance of axles equaling 3 to 3.5 m should be considered. In the same decree, and as horse tramways were already in use, additional design loads were provided. Wagons, drawn by 3 horses were to be calculated with axle loads of 110 kN and 2 wheels, whereas, if they were drawn by 4 horses loads of 160 kN and 4 wheels were to be considered. The mass of each horse was equal to 500 kg. Both schemes are reproduced in fig.6.

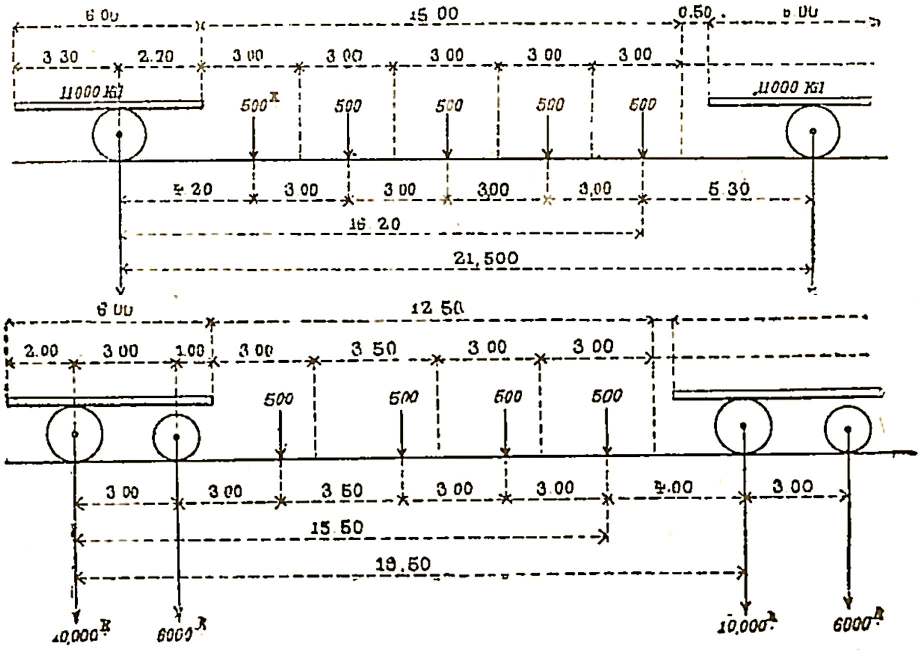

Figure 6: Design load horse tram (top) 3 horses (bottom) 4 horses.

From 1885 motorized tramways were operated. The loads were mostly determined by the steam locomotives. The design loads for these trams were inspired by real trains and had axle values varying from 75 to 95 kN. The lightest scheme can be found in [7] and was unvaried from 1885 to 1974. It is reproduced in fig. 7.

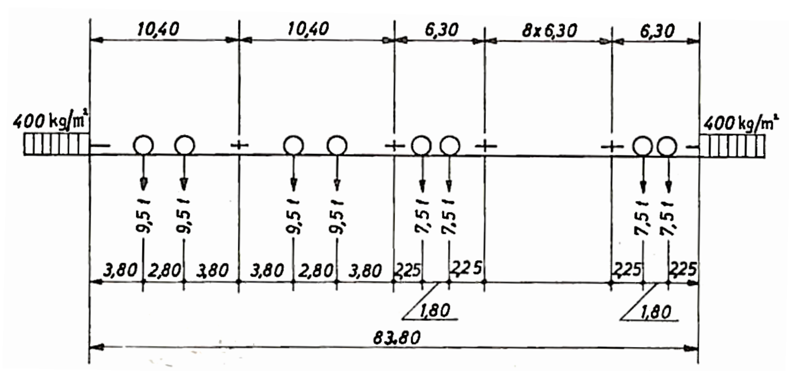

Figure 7: Design load motorized tramways.

The alternative scheme of this series has lighter concentrated loads and is longer than in fig. 7 and thus may be considered less critical. This overview confirms that at the beginning of 20th century, design loads were certainly lighter than today. Therefore, if we want to assess the load-carrying capacity of bridges from this period, the original design load does not allow to conclude on the capacity to support present traffic.

3.2 Design load

Various references have been used for determining the live loads. Among these, Eurocodes EN 1991-2 [4] should be mentioned as well as its Belgian National Annex [8], which is a very useful document. The latter allows verification of existing infrastructure through the use of a realistic LM 5. This LM 5 may replace LM 1 for existing structures, provided the bridge carries local traffic only, which applies to bridges inside historic cities. LM 5 corresponds to one of the frequent lorries of FLM 2. It requires the use of adapted factors such as a combination and an impact factor. If such a model is used, it was felt that it should be supplemented by other loading schemes, from actual loads of trams and buses.

An appropriate modern tram loading has also been considered. As these trams have a metric track width, the distance between wheels equals 1 m. In addition, most bridges are frequently crossed by public transport buses and touristic coaches. A realistic loading scheme for buses obtained from a fabricator was also considered. This scheme includes high knife loads of 135 kN, this being derived from a comprehensive survey, made in 4 EU-countries [9] and stating that official axle loads are frequently exceeded in real traffic. However, this survey was unable to detect which vehicle axle is the heaviest.

4 PORTAL FRAME BRIDGES

4.1 Condition

Three of the oldest bridges in the city, built in view of the world exposition are steel portal frames. As the third one has no further use as road bridge, two of them will be considered. They were built respectively in 1907 and 1912, replacing movable swing bridges, narrowing the passage of vessels and causing interruption of road traffic during opening. In the building period, more precisely from 1901, the Siemens-Martin and Thomas fabrication processes of steel had been developed and all data point towards the material being early age steel [10] [11].

In addition, the portal frame structure allows maximizing the vertical clearance for waterway traffic, by redistributing bending moments from the central part of the span towards the frame nodes. This has been pushed far in the case of the Saint-George Bridge shown in fig. 8 (left). The St-George's bridge was built in 1907 and replaced 2 bridges (Red Tower and Pas bridge). It allows crossing of the river Lys, near to the original confluence. Because of its replacing 2 former crossings, it has excessive width. Its vertical clearance of 3.5 m allows passing of smaller vessels to access the yacht-basin of Ghent, called 'Portus Ganda', a long-term development project of the city.

The Cauldron bridge, built in 1912, shown in fig. 8 (right) crosses the canal, connecting rivers Lys and Scheldt, dug already in the 11th century delimiting the medieval city to the South. It carries road traffic to 2 important squares of the city, the commercial centre and the old court of justice. The bridge is also crossed by the main tramway line of the city.

The two-hinge portal frame of St-George's Bridge was designed, allowing a vertical rounding bend of 136 m in the road. This scheme is shown in Fig. 9. The designers have chosen to build the bridge considerably wider than strictly necessary. This also allowed a straight crossing of the portal frames with the river, thus obtaining minimum span length. In the past, the unnecessary areas of the bridge were used as parking places, whereas today the footpaths are extremely large, the road width being 13 m and the bridge's width equaling 35 m.

Figure 8: Design load motorized tramways.

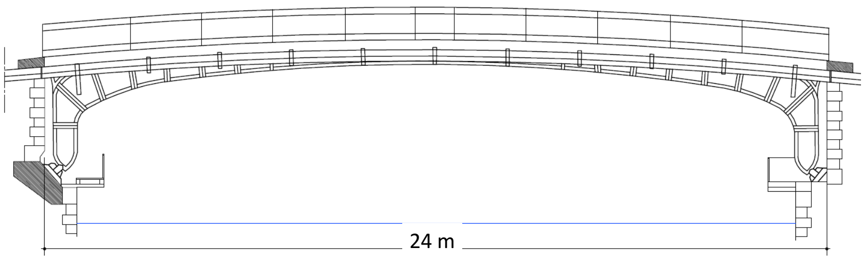

Figure 9: Portal frame.

Both bridges have recently been inspected. The general aspect of both bridges is worrying and corrosion is seen in every detail. However, it is more important to find out whether the steel sections show considerable reduction and to quantify this. Although modern riverside walkways have been installed below both bridges (fig. 8), the corrosion protection has not been renewed since 30 years. For both bridges especially the outside frames are corroded, either the angle profiles of the lower flanges or the top plate of the upper flange. In a single case of a vertical frame post, the complete upper flange is corroded.

These observations have been supplemented at the most critical locations by grinding to blank metal and by measuring the exact length of the main corrosion areas. This enabled to derive exact data of the remaining profile and plate sections and to assemble characteristics of an alternative damaged structure. Superficial deterioration has not been considered in this alternative.

The hinged supports were inspected more in particular. Already fig. 10 shows a rather bad condition. However, after manual brushing, hammering and subsequent local grinding, the corrosion of these parts appeared equally superficial and limited to less than 1 mm. Most probably the hinge is not sufficiently functioning and will require serious refurbishment.

These various inspections clearly showed that the outside frames are heavily corroded at the most exposed parts. At the frame centre, more than half of the lower flange has disappeared, whereas at the portal nodes and posts, the former applies to the upper flanges. At a single inner frame the vertical post is heavily corroded. A detailed inventory of all these reduced cross-sections has been made and was implemented in a numerical model of both bridges.

Figure 10: Corrosion of outside frames and hinged support.

4.3 Assessment results

The use of a detailed numerical model has demonstrated that the effect of concentrated force from loading models is but poorly distributed among the portal frames. This also applies to the crowd loading on the walkways. Hence, the degraded frames carry little or no effect from traffic, and are loaded by the crowd of people standing on the bridge and watching harbour events. Fig. 10 shows plate thickness of the model of St-George's bridge and Table 1 summarizes the unity strength test for the undamaged structure and for the heavily corroded Northern and Southern frames. Obviously, the undamaged structure satisfied the requirements and can resist the relevant loading of trams, buses and lighter trucks, as well as the crowd loading. The degraded frames have insufficient load carrying capacity to resist the crowd load. Consequently, the owner has decided to consider in depth restorations. Various alternatives are possible.

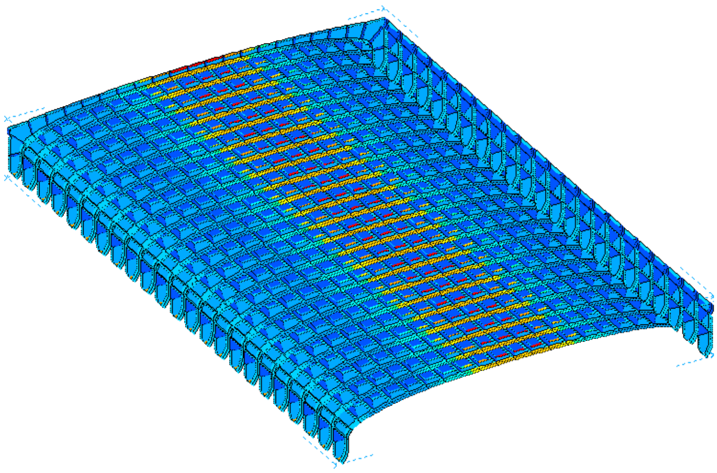

Figure 11: Numerical model of St George bridge.

These results apply to the St-George's bridge. The condition of Cauldron Bridge is better and the use of a similar model as in fig. 11 confirmed that the unity-check of the degraded structure still complies.

5 REFURBISHMENT ALTERNATIVES

The results of calculations clearly showed that, in spite of heavy corrosion, the St George bridge still is capable of carrying realistic loads in normal safety conditions, except for the 1^{st}

and 2nd edge frames, both on the Northern and Southern side of the bridge. Two alternatives may be considered to restore the load-carrying capacity.

Table 1: Unity check for undamaged and corroded structure.

Unity-check	Undamaged structure	Degraded Frame North	Degraded frame South
Span centre upper flange	0.311	0.221	0.206
Span centre lower flange	0.318	0.551	0.361
Frame node upper side	0.461	0.949	0.53
Frame node lower side	0.666	1.251	1.091
Post outside	0.411	0.719	0.349
Post inside	0.966	0.94	0.772

Apart from the possible repair of the outside frames, all other steel parts of the bridge should be grit blasted to obtain corrosion free material. One of the difficulties will be to limit blasting pressure, in this case to 0.17 MPa. If higher pressure is used, the work may be faster, but the risk of damaging further some of the weaker parts may be high. Adequate filler products may be used to repair serrated edges of plates and profiles. The latter also applies to the hinged supports, which will need to be free of dust and blasting material before greasing.

Local replacement of corroded plates or profiles becomes rather difficult, since the original length of the elements mostly covers the entire frame. In addition, if an outside angle profile must be replaced, the opposite will also be disconnected from a member web, since the rivets are connecting both. The difficulty is shown in fig. 11 for a single cross-section at the span centre. This has to be taken into account when a refurbishment process is developed.

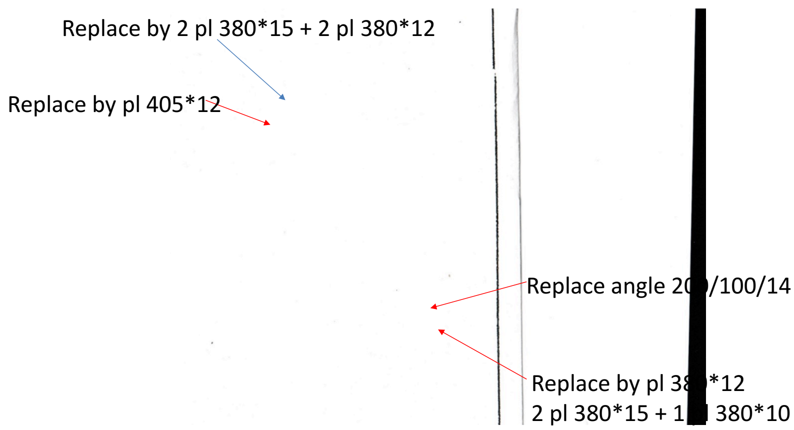

Figure 12: Difficult replacement of plates in riveted section.

Hence, the first alternative would be to replace corroded profiles either on site or at a workshop. If a frame is still connected to the crossbeams and the heavily corroded angles and flanges are removed for replacement and if the new elements are put in place, before connection of these reinforcements a heavily weakened condition will exist. The steel stresses in this temporary situation reach 105.6 MPa due to the dead weight alone. Compared to the stress in the damaged condition, there is an increase of stresses from 14.50 to 117.3 MPa tension at the lower flange at the span centre and from -39.95 MPa to -96.12 at the node. Evidently, these stress increases are unacceptable and the reinforcement on site is not a valid solution, unless temporary supports would be placed in the river bed. Unfortunately, the administrator of the river cannot accept such disturbance in fluvial traffic. Hence, the reinforcement would then require to remove the 4 outer frames by disconnecting them, and subsequently reinforce them at a workshop.

A second alternative, more daring, is to replace the Northern and Southern portal frames by an existing frame from inside the bridge, for instance numbers 4 or 5. These extracted frames would then be replaced by a new, welded portal, to be connected by bolts to the remaining structure. In doing this, the outside appearance of the bridge would remain identical and the structure can satisfy all requirements. However, the detailed design of such a transformation will probably reveal a series of connection problems. In addition, the removal and replacement of the frames introduced temporary stresses of the same magnitude as in the first alternative.

A final alternative would be to apply anti-corrosion treatment on site, without replacing any part of the structure. Instead, the walkway loads may be reduced. Indeed, at present the walkways consist of some 0.40 m of cement-mixed sand and concrete tiles. Most of this may be replaced by lightweight concrete of 11 kN/m³ of 0.32 m thickness and concrete tiles. This reduces the total load by 5.4 kN/m², which is already compensating the lack of load-carrying capacity. This alternative allows to limit procedures to the blasting and repainting as well as cosmetic finishing of jagged edges and injections of open edges and ribs, as well as an adjustment of the composition of the roadway. Obviously, this is far more attractive for the owner. The former applies to the case of the St-George bridge, whereas corrosion damage is much lighter for the Cauldron bridge. However, a similar solution will also apply for this structure.

6 CONCLUSION

Since most original bridges in the city of Ghent have either be replaced, rebuilt according to historic drawings or replaced by modern structures, only those bridges built for the 1913 world exposition are original early age steel structures. Maintenance of these structures has been at low frequency, since it was repeated in average every 30 year. Consequently, each period extensive refurbishment was needed.

Literature research has shown that 19th and early 20th century design loads were either distributed load or inspired by horse tramways and later on by steam power trams. These are considerably lower than required by modern traffic. Hence, assessment of the future use and load carrying capacity of the older bridges required the use of appropriate references, in this case a National Annex to EN 1991-2. This has been supplemented by real traffic data and appropriate load and dynamic factors.

The analysis and assessment of the load-carrying capacity of 2 of the oldest bridges, early age steel portal frames, was carried out, taking into account the damage due to corrosion, found during inspection. The results of the St-George bridge have been discussed and showed insufficient capacity if the corrosion damage is included in the model. However, this insufficiency applies only for 2 of the 23 portal frames, located below the walkways and is due to crowd loading, which actually occurs on this bridge during events. Three alternatives have been considered for increasing the load-carrying capacity of the damaged portal frames. Refurbishment on site by replacing heavily corroded members creates temporary reduction of the frame resistance up to unacceptable increase of steel stress. This cannot be compensated by the final increase in resistance. Hence, reinforcing the weakened frames, requires removing them from the site and carry out the refurbishment at a workshop. Internal shifting of portal frames has similar setbacks as the former alternative.

The final alternative of reinforcing of the structure is to proceed with corrosion protection and to reduce the dead load on the walkways. Calculations have shown the validity of this option, which is preferred by the owner. Refined analysis and the use of detailed numerical modelling, as well as realistic loading schemes, may thus contribute to thorough refurbishment and extended life of 2 historic early-age steel portal frame bridges.

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PROHITECH '17

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3rd INTERNATIONAL CONFERENCE ON PROTECTION OF HISTORICAL CONSTRUCTIONS

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B – T beam and block system slabs. Pillars, beams and foundations are in concrete (construction).

C – Foundation in concrete, beams and pillars in steel structure and steel decking floors slabs.

on support was devised considering a scale of interest ranging from 1 (least interesting) and attributing percentage levels to the analyzed variables [2]. The assigned percentage levels was the following: Factor F1 - 30% for recommendations and ... ent system parameters [1]; Factor F2 - 30% for advantages and disadvantages; ... environmental impact categories quantification [3]. Table 1 presents the percentage choice and calculations results between different options.

Table 1: Calculation results of structural options studied

...n	Factor F1 (30%)	Factor F2 (30%)	Factor F3 (40%)	...
	1	1	3	
	3	2	1	
	2	3	2	

n C has better results and involves the use of a steel structure (beams and pillars and steel decking for concrete floors slabs), figure 1. On the other hand, the option has the lowest results in the quantification of environmental impact categories, ... ne that has the most advantages in relation to the specificities of the building ... ty, quick assembly and is the one that best responds to the existing constraints

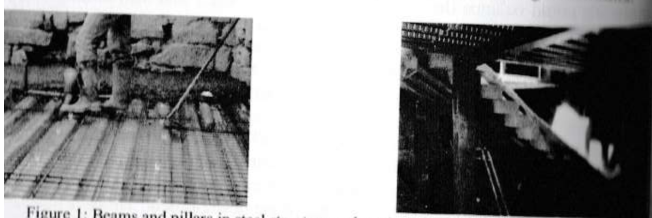

Figure 1: Beams and pillars in steel structure and steel decking for concrete floors slabs

to these facts, Option C allows greater durability and does not require large ... ts during the time frame of the works: demolitions, structure and roofs in 2013 ... s and finishing in 2025. This weighting also allows us to understand that the ... terials makes the intervention more sustainable and with less impact on the environment ... per presents in a simple way the analysis of several requirements that are expected in building rehabilitation projects. In this sense, it sheds more light on the importance ... n. The main goal of this paper is guarantee a more effective response to the ... d constraints of each rehabilitation work, related to planning, deadlines, cost ... n-contractual works, among others, raising a sustainable construction [1].

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12.

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... location at the confluent of rivers Scheldt and Lys and the many canals and ditches, built ... flooding, the historic city of Ghent has many bridges. Their number decreased after ... many waterways. Today, the number of bridges is limited to 124, of variable types. This is ... major event that reshaped many parts of the medieval city, the world exposition of 1913. ... of WW 1 and in view of this event large parts of the city were transformed, several ... buildings and churches were thoroughly refurbished. Among these, movable bridges were ... by fixed crossings. One iconic structure is the vaulted arch of St Michael's bridge, shown

Figure 1: St-Michael's bridge across river Lys.

... of the oldest bridges in the city, built in view of the world exposition are steel portal frames. ... third one has no further use as road bridge, two of them will be considered. They were built ... in 1907 and 1912, replacing movable swing bridges, narrowing the passage of vessels ... interruption of road traffic during opening. In future, two of these bridges will continue ... used for tramways, buses and local traffic, the smallest being Cauldron bridge (fig. 2). ... including grinding and measuring, has revealed that the largest of both bridges does not ... with local traffic requirements. The use of a detailed numerical model has demonstrated ... effect of concentrated force from loading models is but poorly distributed among the portal ... This also applies to the crowd loading on the walkways. Hence, the degraded frames carry ... no effect from traffic, and are loaded by the crowd of people standing on the bridge and ... harbour events.

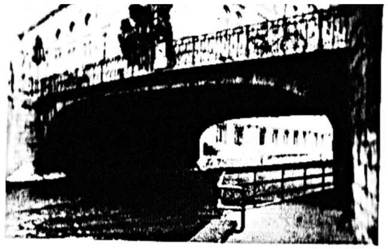

Figure 2: Cauldron bridge : portal frame.

Careful numerical analysis and the use of realistic loading schemes, supplemented [illegible] inspection, has allowed to establish a clear view on the remaining load carrying [illegible] undamaged structure satisfied the requirements and can resist the relevant loading [illegible] and lighter trucks, as well as the crowd loading. The degraded frames have [illegible] carrying capacity to resist the crowd load. Consequently, the owner has decided to [illegible] restorations.

CONCLUSIONS

Since most original bridges in the city of Ghent have either be replaced, rebuilt according [illegible] drawings or replaced by modern structures, only those bridges built for the 1913 [illegible] are original early age steel structures. Maintenance of these structures has been at [illegible] since it was repeated in average every 30 year. Consequently, each period extensive [illegible] was needed.

Literature research has shown that 19th and early 20th century design loads were either [illegible] load or inspired by horse tramways and later on by steam power trams. These are [illegible] lower than required by modern traffic. Hence, assessment of the future use and [illegible] capacity of the older bridges required the use of appropriate references, in this case [illegible] Annex to EN 1991-2. This has been supplemented by real traffic data and appropriate [illegible] dynamic factors.

The analysis and assessment of the load-carrying capacity of 2 of the oldest bridges, early [illegible] portal frames, was carried out, taking into account the damage due to corrosion, [illegible] inspection. The results of the St-George bridge have been discussed and showed [illegible] capacity if the corrosion damage is included in the model. However, this insufficiency [illegible] for 2 of the 23 portal frames, located below the walkways and is due to crowd loading [illegible] actually occurs on this bridge during events. Three alternatives have been considered for [illegible] the load-carrying capacity of the damaged portal frames. Refurbishment on site by [illegible] heavily corroded members creates temporary reduction of the frame resistance up to [illegible] increase of steel stress. This cannot be compensated by the final increase in resistance [illegible] reinforcing the weakened frames, requires removing them from the site and carry [illegible] refurbishment at a workshop. Internal shifting of portal frames has similar setbacks as the [illegible] alternative.

The final alternative of reinforcing of the structure is to proceed with corrosion protection [illegible] reduce the dead load on the walkways. Calculations have shown the validity of this option, [illegible] preferred by the owner. Refined analysis and the use of detailed numerical modelling, as [illegible] realistic loading schemes, may thus contribute to thorough refurbishment and extended life [illegible] historic early age steel portal frame bridges.

[illegible]AFFIC VULNERABILITY OF DEY PALACE STRUCTURE IN THE CASBAH OF ALGIERS

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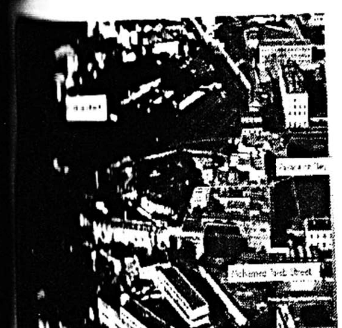
[illegible] Casbah of Algiers, Dey Palace, ambient vibrations, cultural heritage

[illegible]

[illegible] Algiers contains many historical monuments dating from the time when Algeria was [illegible] Ottoman Empire, especially the Citadel located in the Casbah. This Citadel is a set of [illegible] buildings whose Dey Palace is one of them (figure 1). To allow a junction [illegible] the old city (Casbah) and the new city, a road was opened through the Citadel at the end of [illegible] century.

[illegible] consists to estimate the traffic vulnerability of the Dey Palace following observed [illegible] on some masonry walls.

[illegible] vibration recordings were carried out for 24 hours (figure 2). The results of the analysis of [illegible] clearly show that road traffic has a great influence on the stability of the Palace.



[illegible] Aerial photo of the Citadel

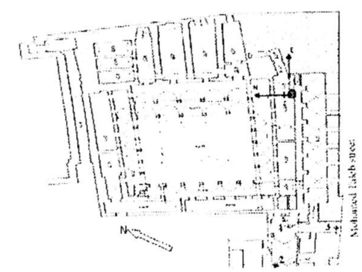


Figure 2: Velocimeter sensor position

[illegible] recordings of the structure of the Palace were performed continuously during 21 hours between [illegible] and 11 31 a.m. the next day (point 4 on figure 2).

[illegible]SION

[illegible] diagnosis reveals that excitations from the street Mohammed Taleb which crosses the Castle [illegible] influence on the structure movements of the Palace of the Dey (figure 3). The structure of the [illegible] and the materials that compose it, essentially cooked bricks bonded with earth mortar, are weakened [illegible] and lack of maintenance increases the degradation. These conditions make the Palace very [illegible] to very low loads like the ones generated by traffic. Some urgent measures can be taken, as [illegible] the traffic in the street and make it one way, building speed bumps or in-ground barriers, before